VOLUME 76 SEPARATE No. 38

OCT 2

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

OCTOBER, 1950

HYDROLOGY OF MEXICO

By Andrés García-Quintero, Assoc. M. ASCE

IRRIGATION DIVISION

Copyright 1950 by the AMERICAN SOCIETY OF CIVIL ENGINEERS
Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N.Y.

TG20.6

PRICE $0.50 PER COPY

The Society is not responsible for any statement made or opinion expressed in its publications

---

Published at Prince and Lemon Streets, Lancaster, Pa., by the American Society of Civil Engineers. Editorial and General Offices at 33 West Thirty-ninth Street, New York 18, N. Y. Reprints from this publication may be made on condition that the full title of paper, name of author, page reference, and date of publication by the Society are given.

Proceedings—Vol. 76 October, 1950 Separate No. 38

AMERICAN SOCIETY OF CIVIL ENGINEERS

Founded November 5, 1852

PAPERS

HYDROLOGY OF MEXICO

By Andrés García-Quintero,[1] Assoc. M. ASCE

Synopsis

Rainfall is the principal source of water in Mexico and the principal factor in its hydrology; consequently the main purpose of this paper is to review the hydrometeorological and geophysical aspects, in order to explain why water, the most precious of all natural resources, is so scarce.

General Description

Geographically, Mexico is between the latitudes 14° north and 33° north within which parallels (both north and south of the equator) the desert belts of the world are known, roughly, to occur (the Sahara Desert in Africa, the Arabia, Iran, and Gobi deserts in Asia, and the American deserts in the northern hemisphere; and the Atacama and Patagonia deserts in South America, the Kalahari Desert in Africa, and the Australian deserts in the southern hemisphere).

In a classification of the areas of the world into areas of relative rainfall, zone 1 being the wettest,[2] the geographic position of Mexico may be considered as zone 4—dry the entire year, between latitudes 19° north and 31° north—that is, more than 75% of the total area is in zone 4; and so, from the geographical point of view, Mexico may be classified as not rainy even when, in some southeastern regions, there are tropical rains and tropical climates.

Orography.—The mountain system of Mexico has been divided into six groups or ranges, extending more or less along the coast lines: (*a*) Sierra Madre Oriental, (*b*) Sierra Madre Occidental, (*c*) Sierra Madre del Sur, (*d*) Sierra Volcanica Transversal, (*e*) Sierra de Chiapas, and (*f*) Sierra de Baja California.

(*a*) Sierra Madre Oriental.—This range of mountains running along the coast of the Gulf of Mexico faces the maritime air masses coming inland from

Note.—Written comments are invited for publication; the last discussion should be submitted by April 1, 1951.

[1] Director, Hydrology Section, Water Resources Ministry of Mexico, Mexico D. F., Mexico.

[2] "Introduction to Meteorology," by Sverre Petterssen, 1st Ed., McGraw-Hill Book Co., Inc., New York, N. Y., 1941.

the Gulf of Mexico, the Caribbean Sea, or the Atlantic Ocean (see Fig. 1). Its rapid increase of altitude from sea level to more than 7,250 ft results in a total decrease in temperature of nearly 20° F (a 1° F drop for every 366-ft increase in altitude). This topographic environment produces abundant condensation and rainfall on the windward side of the mountains; and, as the stream of humid, warm air masses is more or less permanent all the year, this coastal region receives the greatest rainfall in Mexico. On the other side of the mountains, in the central plateau, the rainfall is reduced to the minimum and increases again on the east flanks of the other mountain system known as the Sierra Madre Occidental.

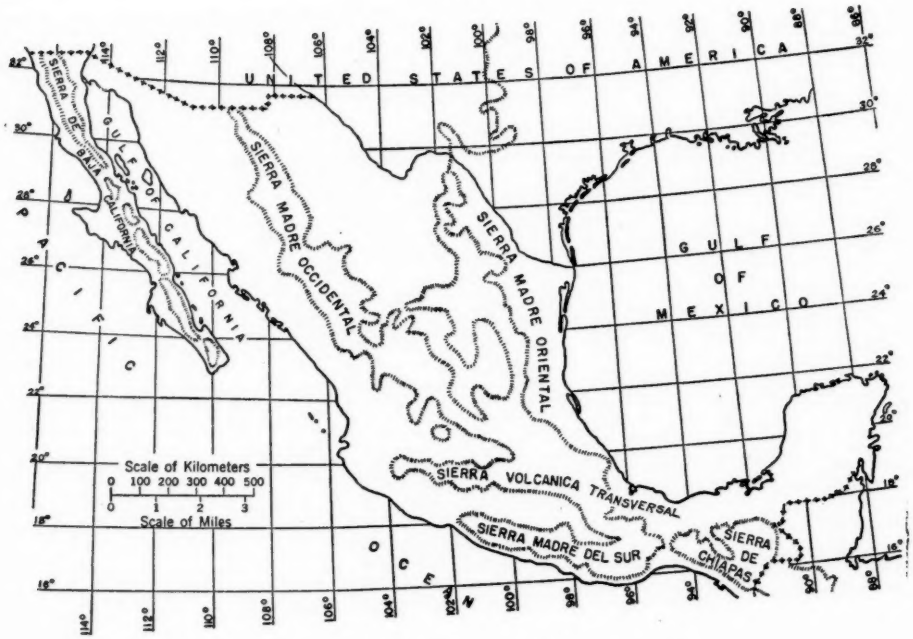


FIG. 1.—PRINCIPAL OROGRAPHIC SYSTEMS IN MEXICO

(*b*) Sierra Madre Occidental.—These mountains, extending along the Pacific Coast of Mexico from the State of Nayarit northward and beyond the international line, are the Mexican part of the range known in the United States as the Continental Divide. The effects of these mountains are the same as those described for the Sierra Madre Oriental except that the western currents are limited to the summer months. Consequently this coastal region is secondary to region (*a*) in terms of mean annual rainfall.

(*c*) Sierra Madre del Sur.—This mountain range runs from the Tehuantepec Isthmus through Oaxaca and Guerrero states in a general direction which parallels the air currents of the Pacific and which is not favorable for rainfall production. Only the minor branches of this system have topographic effects on the humid air masses coming from the west, as a result of which the southern

coasts of Mexico have the lowest precipitation. Also, this condition explains why in the Balsas River Basin, surrounded by mountains with peaks more than 8,200 ft high, the rainfall is least in the lower valleys where arid and desert climates are found and highest in the cool climates in the higher parts.

(*d*) Sierra Volcanica Transversal.—These mountains embrace a belt that starts at Zempoáltepec, Oaxaca, and that, in a general direction to the west, goes on to the Pacific Coast. This orographic system is also known as the Volcanic Tranverse Mountains because all the active volcanoes, or those of relative recent age, are found along latitude 19° north. The principal volcanoes from west to east are: Jorullo, in the State of Colima; Paricutin, in the State of Michoacan; Toluca Nevado, Popocatepetl, Iztaccihuatl, and Ajusco, in the State of Mexico; and Citlaltepetl, in the State of Veracruz. Because the southern side of these mountains receives the humid air currents from the Pacific, the major rainfall occurs there, even when a part of the precipitation is discharged on the coastal side of the Sierra Madre del Sur.

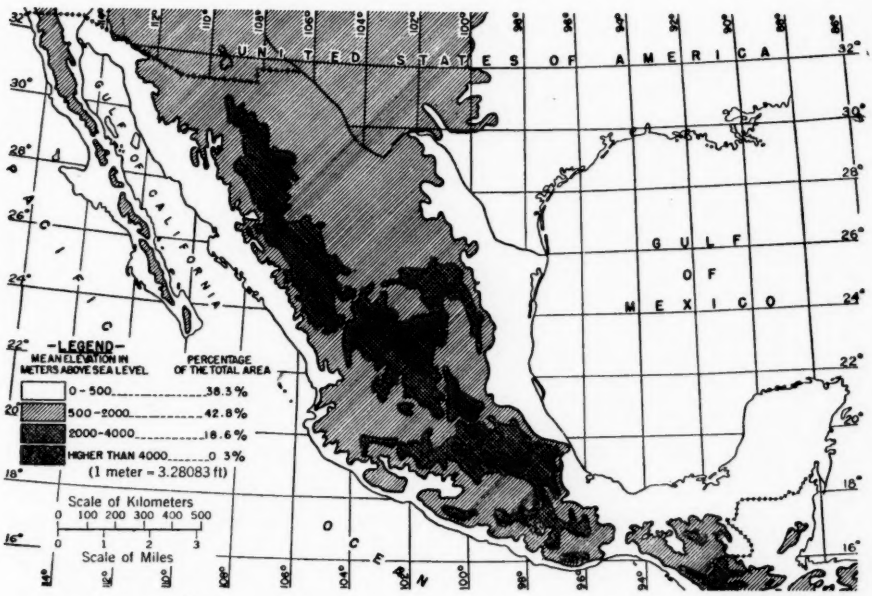


FIG. 2.—MEAN ALTITUDES OF MEXICO

(*e*) Sierra de Chiapas (Chiapas Mountain System).—This range is part of the Continental Divide extending northward from Central America. Its geographical position between the air flows of the Caribbean Sea on the north and those of the equatorial areas of the Pacific Ocean on the south assures abundant condensation and precipitation. In this mountain range (or in its vicinity) the maximum point rainfall has been observed in Mexico, reaching an average of more than 177 in. per year. It is notable in Fig. 2 that the coastal plains on the Pacific Coast (El. 0 to 500 meters or 1,645 ft) are narrower than

those on the coast of the Gulf of Mexico and that the narrowest coastal plains are on the South Pacific Coast and along both sides of the lower California Peninsula.

Air Masses and Fronts

An important percentage of rainfall in the northern part of Mexico has its source in the continous "battle fronts" of air masses from polar continents and seas coming in contact with air masses from equatorial areas. Sverre Petterssen has published graphic illustrations of the air-mass sources for the northern hemisphere in summer[3] and in winter.[4]

In winter months the air masses that enter Mexico are:

(1) Those from the great American plains, permeated with snow or frost;

(2) Those from the Atlantic Ocean, formed by tropical maritime air, which is humid and warmer than air that has passed over land; and

(3) Air masses from the Pacific Ocean, in the months of December, January, and February, passing through the states of California and Arizona in the United States to the states of Sonora, Sinaloa, Durango, and Chihuahua in Mexico. These air masses strike the high mountains of the Sierra Madre Occidental, precipitating rains of the cloudburst type which have produced the maximum discharges ever to be observed in the hydrological history of the rivers in these states.

During summer months the origins of the air masses are:

(4) Those coming from the Atlantic Ocean, West Indies, and the Gulf of Mexico—the maritime, warm tropical, and humid air masses being the most important sources of water for Mexico, because more than 80% of the rainfall comes with these winds.

(5) Those from the South Pacific Ocean or the West Pacific Ocean.

Cyclones

Tropical cyclones are so significant in relation to the rainfall in Mexico in the late summer season that it is important to include them among the essential factors in the hydrology of some of the most important rivers. The origin of these low-pressure areas, with their accompanying terrifically high wind velocities and high rainfall intensities, is the Caribbean Sea in the West Indies, along the equatorial doldrums. Their general path flows to the west and passes over the Yucatan Peninsula. Then, in the Gulf of Mexico, it deviates to the northwest, going inland at the coast of the State of Tamaulipas or at the northern coast of the State of Veracruz in Mexico or through the states of Texas, Louisiana, Mississippi, Alabama, and Florida in the United States. The cyclonic season generally covers the months of August and September, but storms of maximum intensity have occurred in the last days of August or in the first days of September.

[3] "Weather Analysis and Forecasting," by Sverre Petterssen, McGraw-Hill Book Co., Inc., New York, N. Y., 1940, p. 160, Fig. 89.

[4] *Ibid.*, p. 165, Fig. 90.

Since a cyclone is an enormous low-pressure area, several hundred miles in extent, all the air masses in the areas contiguous to it tend to be drawn in. In terms of rainfall this tendency means:

1. There is an abnormal increase in rains all along the parts of the cyclone;
2. When the cyclone is intense, the beneficial effects of its rain load are practically reduced to nothing and the damages from flooding residential, industrial, and farm lands are tremendous. (Examples of the catastrophic nature of these revolving monsters are the storms of August 29, 1909, and August 29, 1938, coming from the Caribbean Sea. After the cyclones crossed the Gulf of Mexico, their natural violence was increased by the steep slopes of the Sierra Madre Oriental, which precipitated cloudbursts and flood conditions).
3. The major cyclones occur in the summer months, when there is maximum evaporation from the equatorial land area and sea surface; also, at this time of the year, Mexico receives the greatest proportion of the humid air masses from the eastern bodies of maritime water.

When a cyclone is being generated in the Caribbean Sea or in the Gulf of Mexico, many of the air currents swirl into the cyclone center, leaving the Mexican sky clear—without clouds and without rainfall—for many days and even weeks. When the cyclone is "on the march," however, it is a most calamitous threat, rather than a beneficial factor, in the production of rainfall. In planning hydraulic works for conservation and for the use of surface waters, cyclones impose very unfavorable conditions, requiring very large spillway and flood-control capacities.

Factors That Affect Rainfall

From the preceding description it is possible to determine in advance the magnitude, geographical distribution, and seasonal distribution of rainfall. Rainfall is maximum along the coastal lands of the Gulf of Mexico, especially in the southern parts of the states of Veracruz, Tabasco, and Campeche; it is high along the Pacific coast from the State of Nayarit to the State of Sinaloa; and it is least on the southern coast of the Pacific Ocean. Low rainfall is observed on the Central Pleateau, with high rates in the southern and western parts. The lightest rains are observed to the north in the states of Coahuila, Sonora, and Baja California; this region is similar geographically to western Texas, New Mexico, Arizona, and southeastern California in the United States.

Most of the rains in Mexico are "topographic" in character—that is, they are precipitated by mountain systems. There are rains caused by fronts in the constant clashes of air masses such as when the tropical maritime areas impinge upon masses coming from the cold polar regions of the north; these rains are observed in winter in the northern and northwestern parts of Mexico.

The occurrence of precipitations of convective origin is observed in humid regions such as the states of Veracruz, Tabasco, and Campeche; in the Yucatan Peninsula, where there are no mountains, the rainfall is semiconvective because the high temperature of the sun-heated lands produced vertical air flows which are replaced by humid air masses coming from the east. When these ascending

currents reach a critical altitude and temperature, relatively high rainfall results.

Cyclonic rains are observed along the paths of hurricanes; the areas more seriously affected are the northeastern part of Mexico, the Yucatan Peninsula, the central coastal region of the Gulf of Mexico, the Isthmus of Tehuantepec, the Western Pacific Coast, and the southern extreme of Lower California.

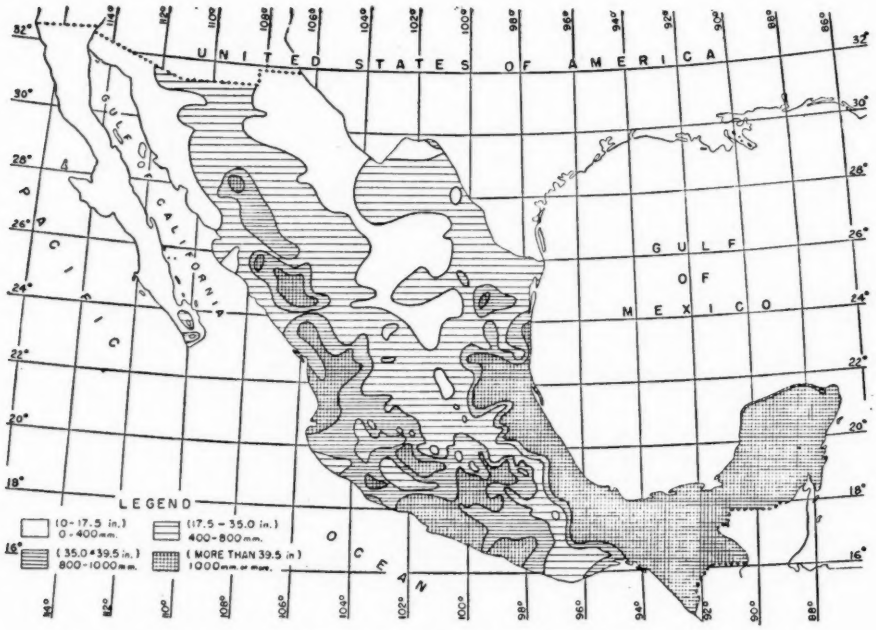


FIG. 3.—MEAN ANNUAL RAINFALL, 1921 TO 1944

MEAN ANNUAL RAINFALL

The mean annual rainfall for the period from 1921 to 1944, inclusive, shown in Fig. 3, was prepared from rainfall records obtained at the stations indicated by dots in Table 1. To orient the reader, the state boundary lines are also shown, with corresponding identity and official abbreviations. To show the seasonal distribution, some rainfall stations were selected as typical of the various areas in Mexico, and the monthly distribution for these stations is shown in Fig. 4. More than 75% of the annual rainfall occurs in the summer months of June, July, August, and September; only in the northern part of lower California does most of the precipitation occur in the winter months of December, January, February, and March. In Fig. 5, the shaded areas indicate a monthly mean rainfall of 25 mm or 1 in.

RAINFALL BY HYDROGRAPHIC REGIONS

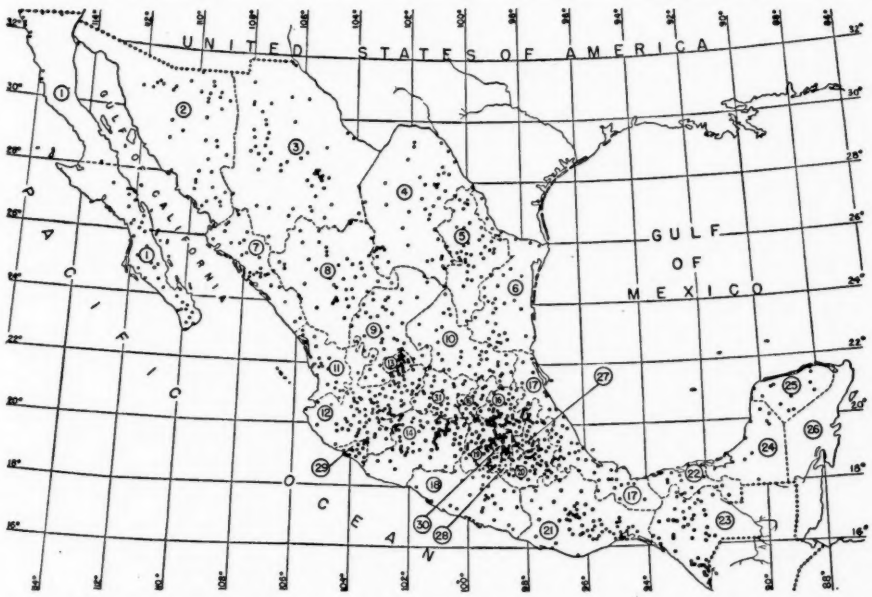
With the foregoing descriptions in mind, Mexico can be divided into a relatively large number of regions in terms of the difference in climate, as

affected by altitude, mountains, and air currents. Mean annual rains for every region are summarized in Table 2, Cols. 4 and 5.

Surface Runoff

The amount of rainfall, its variations and distribution, both geographical and seasonal, combined with the geophysical factors of geographical position,

TABLE 1.—The United States of Mexico: Their Names, Official Abbreviations, and Relative Distribution of Rainfall Stations



No. (1)	Name (2)	Abbr.[a] (3)	No. (1)	Name (2)	Abbr.[a] (3)	No. (1)	Name (2)	Abbr.[a] (3)
1	Baja California	B.C.	12	Jalisco	Jal.	22	Tabasco	Tab.
2	Sonora	Son.	13	Aguascalientes	Ags.	23	Chiapas	Chis.
3	Chihuahua	Chih.	14	Michoacan	Mich.	24	Campeche	Camp.
4	Coahuila	Coah.	15	Querétaro	Qro.	25	Yucatan	Yuc.
5	Nuevo Léon	N.L.	16	Hidalgo	Hgo.	26	Quintana Roo	Q.R.
6	Tamaulipas	Tams.	17	Veracruz	Ver.	27	Tlaxcala	Tlax.
7	Sinaloa	Sin.	18	Guerrero	Gro.	28	Morelos	Mor.
8	Durango	Dgo.	19	Mexico	Mex.	29	Colima	Col.
9	Zacatecas	Zac.	20	Puebla	Pue.	30	Distrito Federal	D.F.
10	San Luis Potosi	S.L.P.	21	Oaxaca	Oax.	31	Guanajuato	Gto.
11	Nayarit	Nay.						

[a] Official abbreviation

topography, air masses, and fronts, as well as cyclonic disturbances, result in surface runoff properties more or less similar to those known by American civil engineers who have worked for hydraulic developments in the southwestern United States. In general, the characteristics of Mexican rivers are: (*a*)

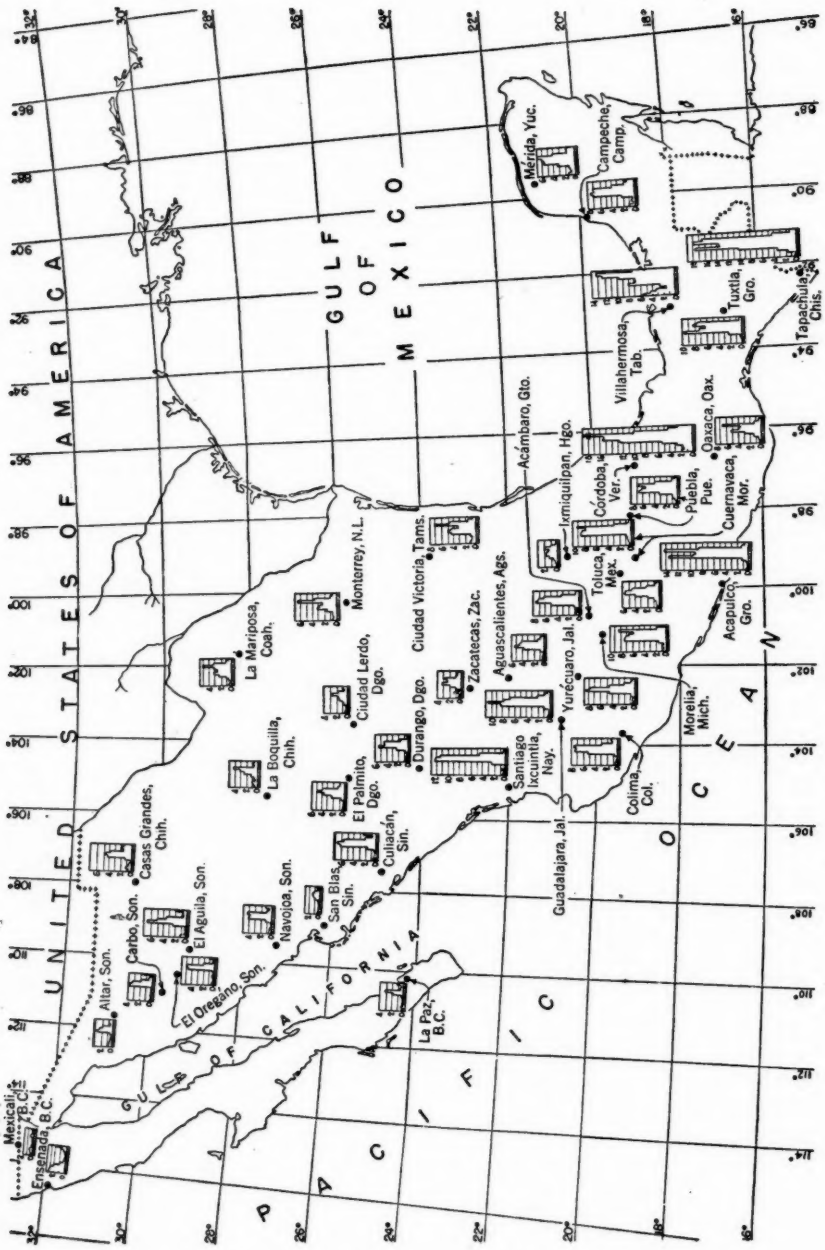


FIG. 4.—MONTHLY DISTRIBUTION OF RAINFALL, IN INCHES

Intermittent currents with the highest percentage of runoff occurring during summer months; (*b*) very small or no discharge in the low-water season; (*c*) very rapid floods with great discharges; and (*d*) long periods of drought during several years, in many basins in the Northern Central Plateau and in the northwestern region. There are only three of four navigable rivers emptying into the Gulf of Mexico; and, in the case of the remainder of the rivers, it is not possible to hope for perennial discharges.

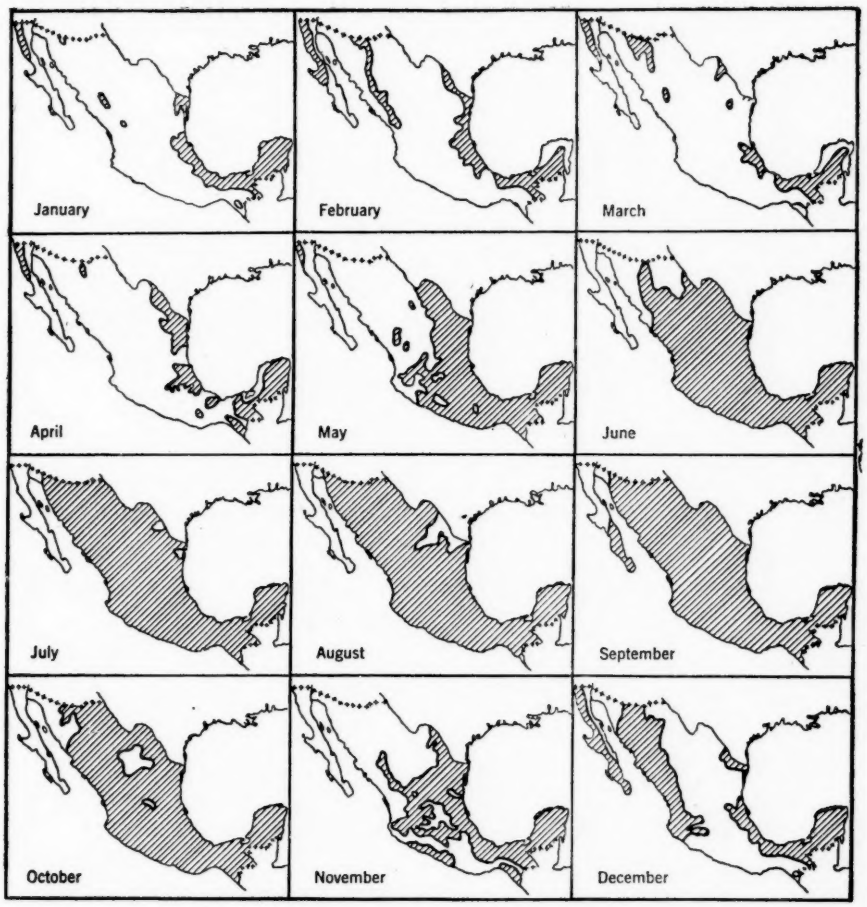


FIG. 5.—GEOGRAPHICAL DISTRIBUTION OF MONTHLY RAINFALL

In the states of Sonora and Sinaloa there are years in which the winter rainfall produces great flood conditions in all the rivers, and maximum discharges have been observed in these winter months.

To measure the surface runoff of its rivers, Mexico has established (through its Water Resources Ministry) an hydrometric service with nearly 450 mea-

TABLE 2. —RAINFALL AND RUNOFF IN MEXICO

No.	Region	Area, in square miles	MEAN ANNUAL RAINFALL		MEAN ANNUAL RUNOFF	
			Volume, in thousands of acre-feet	Depth, in inches	Volume, in thousands of acre-feet	Percentage
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	Northwestern	183,480	174,300	17.8	17,820	12.1
2	Mid-Pacific (including Balsas basin)	126,300	226,190	33.6	21,170	14.4
3	South Pacific	36,300	97,280	50.3	6,680	4.5
4	Northeast (including Rio Grande in Mexico)	149,870	184,840	23.1	12,840	8.7
5	Gulf of Mexico	83,820	297,530	66.6	85,680	58.3
6	Yucatan Peninsula	47,130	136,200	54.2	...	...
7	North Central Plateau	21,250	16,210	14.3	1,720	1.2
8	South Central Plateau	107,770	99,960	17.4	1,170	0.8
	Total	755,920	1,232,510	30.6	147,080	100.0

TABLE 3.—ANNUAL MAXIMUM, MINIMUM, AND AVERAGE RUNOFF OF TYPICAL RIVERS IN MEXICO

No.	Region	River and Site	Drainage area, in square miles	ANNUAL RUNOFF IN THOUSANDS OF ACRE-FEET			Period
				Maximum	Minimum	Average	
1	Northwestern	Yaqui at Tecori	28,420	3,800	1,180	2,240	1929–1945
2	Mid-Pacific	Culiacan at Culiacan	6,290	5,090	1,300	3,100	1924–1945
3	South Pacific	Tehuantepec at Las Euvas	3,480	2,690	290	1,070	1936–1945
4	Northeast	San Juan at Azucar Dam	11,420	3,390	330	990	1924–1943
5	Gulf of Mexico	Tonto at Temascal Dam[a]	1,270	8,700	4,490	2,340	1927–1948
6	North Central Plateau	Nazas at Palmito Dam	6,990	1,970	270	1,070	1929–1945
7	South Central Plateau	Lerma at Tepuxtepec Dam	2,400	1,189	235	544	1932–1945

[a] Estimated with annual rainfall, drainage area, and 2 years of complete observed data.

TABLE 4.—MEAN ANNUAL RUNOFF (THOUSANDS OF ACRE-FEET) IN THE UNITED STATES

Description	North Atlantic	South Atlantic and Gulf	Saint Lawrence	Mississippi	Western Gulf	Colorado	Great Basin	Columbia	California	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Runoff	94,110	112,940	16,510	416,280	25,920	13,030	2,360	169,400	38,370	888,920
%	10.6	12.7	1.9	46.8	2.9	1.5	0.2	19.1	4.3	100.0

TABLE 5.—RELATION BETWEEN THE AVERAGE ANNUAL RUNOFF FOR THE UNITED STATES AND MEXICO

Table	Country	Area, in square miles	Runoff, in thousands of acre-feet	Unit runoff, in acre-feet per square mile
(1)	(2)	(3)	(4)	(5)
2	Mexico	755,930	147,060	194,541
4	United States	3,026,790	888,920	293,684
United States / Mexico		4.00	6.04	1.51

surement stations, located in basins with an area equivalent to 40% of the total land area of Mexico (see Table 2). An idea of the annual variation in some of the typical rivers is given in Table 3.

Data on the hydraulic surface resources of the United States are presented in Table 4.[5] Table 5 indicates that the United States, with an area

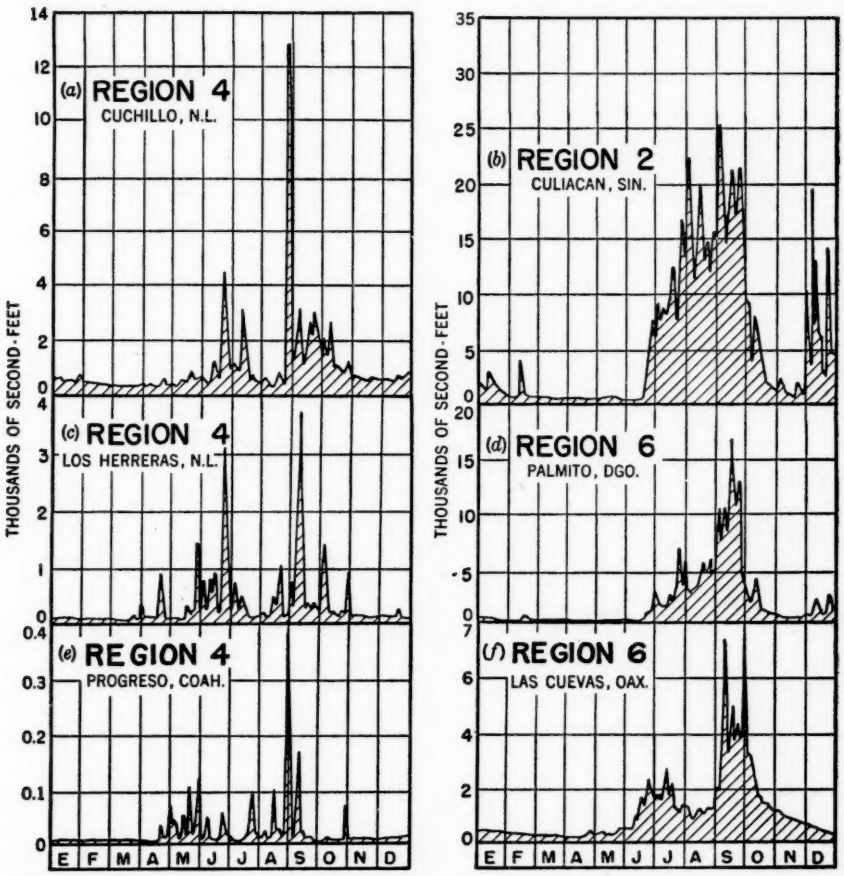


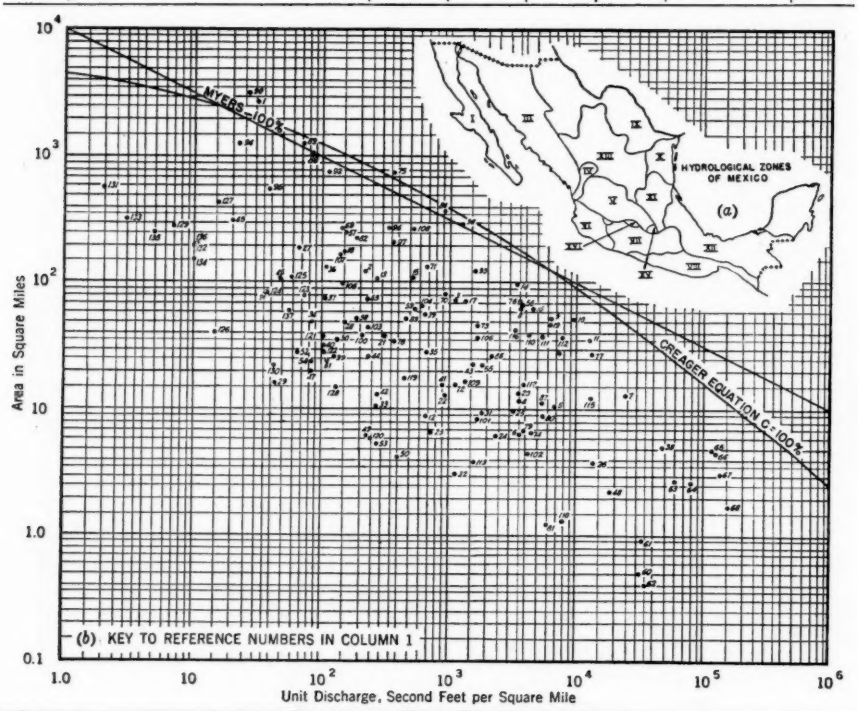
Figure	River	Gaging station[a]	Period of record	Area[b]
a	San Juan	Cuchillo, N.L.	1934–1943	3,570
b	Culiacan	Culiacan, Sin.	1934–1943	6,290
c	San Juan	Los Herreras, N.L.	1940–1943	6,900
d	Nazas	Palmito, Dgo.	1934–1943	6,990
e	Nadadores	Progreso, Coah.	1937–1943	6,060
f	Tehuantepec	Las Cuevas, Oax.	1936–1943	3,480

[a] See Table 1. [b] Drainage area, in square miles.

FIG. 6.—HYDROGRAPHS OF SOME TYPICAL MEXICAN RIVERS

[5] "Floods; Their Hydrology and Control," by H. K. Barrows, McGraw-Hill Book Co., Inc., New York, N. Y., 1st Ed., 1948, p. 52.

TABLE 6.—Maximum Discharges Observed in Mexico



Reference No.[a]	River and site	Drainage area (sq miles)	Discharge (Cu ft per sec)	Discharge (Cu ft per sec per sq mile)	Myers rating, p (%)	Date	Authority[b]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	(c) Lower California, Zone I[c]						
1	Cajoncito at Cajoncito dam site, B. C.	31	85,602	27,61.4	154.0	Sept. 11, 1941	CNI
2	Mulejé at Mulejé dam site, B. C.	216	26,486	122.6	18.0	Sept. 13, 1941	CNI
	(d) North Pacific, Zone III						
3	Altar, Altar, Son.	1,120	81,223	72.5	24.3	Aug. 2, 1939	CNI
4	Sonora, El Orégano, Son.	3,508	40,859	11.6	6.9	Sept. 27, 1943	CNI
5	Bavispe, La Angostura Dam, Son.	6,988	73,525	10.5	8.8	Sept. 8, 1932	CNI
6	Papigochic, La Junta, Chih.	3,552	22,743	6.4	3.8	July 25, 1938	CNI
7	Yaqui, El Aguila, Son.	24,749	324,187	13.1	20.6	Dec. 24, 1914	CNI
8	Mayo, Los Mezcales, Son.	3,745	240,139	64.1	39.3	Dec. 24, 1914	CNI
9	Fuerte, Sn. Francisco, Sin.	6,332	324,893	51.3	41.9	1919	CNI
10	Fuerte, Huites, Sin.	9,861	507,681	51.5	51.2	Dec. 9, 1943	CNI
11	Fuerte near San Blas, Sin.	12,841	447,611	34.9	39.5	Dec. 9, 1943	CNI
12	Ocoroni Creek near Naranjo, Sin.	695	61,306	8.8	23.3	Oct. 11, 1943	CNI
13	Cabrera Creek near Zopilote, Sin.	274	28,923	105.6	17.5	Oct. 11, 1943	CNI
14	Sinaloa at Jaina dam site, Sin.	3,421	328,425	96.0	56.2	Dec. 9, 1943	CNI
15	Mocorito near Guamuchil, Sin.	517	54,737	105.9	24.1	Sept. 26, 1943	CNI
16	Humaya near Palos Blancos, Sin.	4,734	294,523	62.2	42.9	Dec. 9, 1943	CNI
17	Tamazula at Sanalona dam site, Sin.	1,390	98,881	71.1	19.1	Oct. 8, 1945	CNI
18	Bledal Creek at Bledal, Sin.	150	27,404	182.7	22.4	Dec. 9, 1943	CNI
19	Culiacán, at Culiacán, Sin.	6,283	388,460	61.8	49.1	Dec. 9, 1943	CNI
20	San Lorenzo near Santa Cruz, Sin.	3,549	79,281	22.3	13.3	....	CNI

TABLE 6.—(*Continued*)

Reference No.[a]	River and site	Drainage area (sq miles)	Discharge (Cu ft per sec)	Discharge (Cu ft per sec per sq mile)	Myers rating, *p* (%)	Date	Authority[b]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	(*e*) San Pedro River Basin, Zone IV						
21	Santiago near Refugio Salcido, Dgo.	320	12,007	37.5	6.7	Oct., 1943	CNI
22	El Tunal near San Felipe, Dgo.	937	11,936	12.7	3.9	Oct., 1943	CNI
23	La Sauceda at Peña Blanca, Dgo.	727	4,873	6.7	1.8	Sept., 1944	CNI
	(*f*) Lerma-Santiago River Basin, Zone V						
24	Lerma at Tepuxtepec Dam, Mich.	2,400	14,691	6.1	3.0	Aug., 1935	CNI
25	Lerma at Solis Dam, Gto.	3,239	31,077	9.6	5.5	Oct. 12, 1941	CNI
26	Lerma at Yurecuaro, Mich.	13,827	51,277	3.7	4.3	Sept., 1926	CNI
27	Tarandacuao near Tarandacuao, Gto.	69	13,102	189.9	15.8	July, 1931	CNI
28	Tigre Creek near Munguía, Gto.	154	7,663	49.8	6.2	Sept., 1941	CNI
29	Casa Blanca near Casa Blanca, Mich.	43	706	16.4	1.1	Sept., 1934	CNI
30	Tlalpujahua near Pateo, Mich.	135	4,732	35.1	4.1	July, 1935	CNI
31	Laja at Begonia dam site, Gto.	1,815	16,880	9.3	4.0	Sept., 1944	CNI
32	Turbio at Las Adjuntas, Gto.	1,168	3,567	3.1	1.0	Sept., 1944	CNI
33	Duero at Zamora, Mich.	272	2,860	10.5	1.7	Sept., 1939	CNI
34	Tlazazalca at Urepetiro, Mich.	85	4,202	49.4	4.6	Sept., 1943	CNI
35	Lagos at Cuarenta Dam, Jal.	695	19,635	28.3	7.5	Sept., 1944	CNI
36	Teocaltiche near Calera, Jal.	113	14,867	131.6	14.0	July 13, 1937	CNI
37	Del Valle, near Valle de Guadalupe, Jal.	112	8,299	74.1	7.8	June 23, 1941	CNI
38	Santiago at Yago, Nay.	47,876	239,114	5.0	10.9	Oct., 1943	CNI
	(*g*) Midpacific, Zone VI						
39	Ayuquila near Tacotán, Jal.	658	37,645	57.2	14.7	Sept., 1944	CNI
40	Tapalpa at El Nogal, Jal.	113	3,531	31.2	3.3	Aug., 1944	CNI
41	Tuxpan near Quito, Jal.	900	13,702	15.2	4.6	Sept., 1944	CNI
	(*h*) Balsas River Basin, Zone VII						
42	Atoyac near El Carmen, Pue.	291	3,602	12.4	2.1	July, 1940	CNI
43	Atoyac at Tejaluca, Pue.	1,559	34,926	22.4	8.9	1919	CNI
44	Zahuapan at Panotla, Tlax.	242	6,321	26.1	4.1	Sept. 23, 1941	CNI
45	Tembembe at Tembembe, Mor.	49	5,368	109.6	7.7	June, 1935	CNI
46	Cotija, at Cotija, Mich.	20	6,109	305.5	13.7	July, 1936	CNI
47	Quitupan at Quitupan, Jal.	85	1,660	19.5	1.8	Sept., 1944	CNI
48	Balsas at Mezcala, Gro.	18,218	41,777	2.3	3.1	Oct. 5, 1941	CFE
49	Valle de Bravo at Valle de Bravo, Mich.	232	1,413	6.1	0.9	Aug. 21, 1942	CFE
50	Malacatepec at Malacatepec, Mich.	405	1,660	4.1	0.8	Sept. 27, 1943	CFE
51	Verde at Station No. 4.	116	2,790	24.1	2.6	June 28, 1943	CFE
52	Ixtapan del Oro at Station No. 7.	66	1,872	28.4	2.3	Sept. 5, 1943	CFE
53	El Salitre at Station No. 5, Mich.	280	1,519	5.4	0.9	Sept. 25, 1943	CFE
54	Cupatitzio at Station No. 9, Mich.	85	1,942	22.8	2.1	July 3, 1941	CFE
	(*i*) South Pacific, Zone VIII						
55	Tehuantepec near Nejapa, Oax.	1,795	38,846	21.6	9.2	Sept., 1944	CNI
56	Tehuantepec at Tehuantepec, Oax.	3,660	247,202	67.5	40.9	Sept., 1944	CNI
57	Los Perros Creek at Ixtepec, Oax.	154	38,493	250.0	31.0	Sept., 1944	CNI
58	Chicapa near Union Hidalgo, Oax.	193	10,065	52.2	7.2	Sept., 1944	CNI
59	Suchiate at Paso de Guarumaro, Chis.	564	34,290	60.8	14.4	Sept. 22, 1944	CNI

TABLE 6.—(*Continued*)

Reference No.[a]	River and site	Drainage area (sq miles)	Discharge		Myers rating, p (%)	Date	Authority[b]
			(Cu ft per sec)	(Cu ft per sec per sq mile)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	(*j*) Rio Grande Basin in Mexico and International Line, Zone IX						
60	Grande at Fort Quitman, Tex.	31,990	16,986	0.5	0.9	June 20, 1905	IBC
61	Grande at La Nutria, Tex.	33,924	30,017	0.9	1.6	....	IBC
62	Grande at Presidio Arriba, Tex.	35,000	15,185	0.4	0.8	June 12, 1912	IBC
63	Grande at Presidio Abajo, Tex.	59,767	162,094	2.7	6.6	Sept. 11, 1904	IBC
64	Grande at Langtry, Tex.	79,298	204,118	2.6	7.3	June 18, 1922	IBC
65	Rio Grande at Del Rio, Tex.	121,513	600,347	4.9	11.3	Sept. 1, 1932	IBC
66	Rio Grande at Eagle Pass, Tex.	125,261	568,563	45.	16.1	Sept. 2, 1932	IBC
67	Rio Grande at Laredo, Tex.	130,616	402,585	3.1	10.9	Sept. 3, 1932	IBC
68	Rio Grande at Zapata, Tex.	154,184	261,327	1.7	6.7	Sept. 4, 1932	IBC
69	Las Vacas Creek at Villa Acuña, Coah.	146	39,199	268.5	32.5	April 5, 1940	IBC
70	San Diego near Jimenez, Coah.	931	75,220	80.8	24.7	Sept. 18, 1941	IBC
71	San Rodrigo, near El Mural, Coah.	586	81,223	138.6	33.6	Sept. 7, 1932	IBC
72	Escondido at Villa de Fuerte, Coah.	1,130	17,693	15.7	5.3	May 14, 1935	IBC
73	Alamo near Ciudad Mier, Tams.	1,675	76,632	45.8	18.8	Sept. 7, 1933	IBC
74	Salinas at Cienega de Flores, N. L.	454	30,194	6.6	4.5	May, 1941	CNI
75	Station Catarina at Monterrey, N. L.	366	278,031	759.6	145.6	Aug. 26, 1909	ENR
76	San Juan at El Cuchillo, N. L.	3,578	252,922	70.7	42.3	Aug. 29, 1938	CNI
77	San Juan at Santa Rosalia, Tams.	13,000	353,145	27.2	31.0	Aug. 30, 1909	IBC
78	Pilon at Montemorelos, N. L.	366	127,132	34.7	66.6	Aug. 30, 1938	CNI
79	San Pedro at Villalba, Chih.	3,838	26,521	6.9	4.3	Sept., 1942	CNI
80	Sabinas at Sabinas, Coah.	5,471	48,663	8.9	6.6	Aug., 1944	CNI
81	Nadadores near Progreso, Coah.	6,027	7,098	1.2	0.9	Sept., 1944	CNI
82	Parral, at Parral, Chih.	187	42,377	226.6	31.0	Sept. 8, 1944	CNI
83	Florido near San Gabriel, Dgo.	480	24,720	51.5	11.3	Sept. 7, 1944	CNI
84	Florido near San Antonio, Dgo.	913	33,549	367.5	11.1	Sept. 7, 1944	CNI
85	Primero near Mouth Rio Florido, Dgo.	230	17,657	76.8	10.5	Sept. 7, 1944	CNI
86	Florido near Corrales, Chih.	2,174	56,503	26.0	12.1	Sept. 8, 1944	CNI
	(*k*) North of Gulf of Mexico, Zone X						
87	San Fernando near San Fernando, Tams.	5,452	61,730	11.3	8.4	Aug., 1938	CNI
88	Camacho at Bridge in Road No. 1, N. L.	86	91,217	1,060.7	98.5	Aug., 1938	DNC
89	Ramos at Bridge in Road No. 1, N. L.	71	89,875	1,265.8	106.7	Aug., 1938	DNC
90	Blanquillo at Bridge in Road No. 1, Tams.	27	86,379	3,199.2	166.4	Aug., 1938	DNC
91	Lajas at Bridge in Road No. 1, Tams.	36	3,037	84.4	5.1	Aug., 1938	DNC
92	Linares near Linares	119	90,052	756.7	82.6	Aug., 1938	DNC
93	Purificación near Barretal, Tams.	1,559	193,170	123.9	49.0	Aug., 1938	CNI
94	La Presa at Bridge in Road No. 1, Tams.	22	27,369	1,244.0	58.5	Aug, 1938.	DNC
95	San Marcos at Bridge in Road No. 1 Tams.	39	22,601	579.5	36.2	Aug., 1938	DNC
96	Santa Engracia at Road No. 1., Tams.	339	92,171	271.9	50.1	Aug., 1938	DNC
97	Cabezones at Bridge in Road No. 1 Tams.	354	73,666	208.1	39.2	Aug., 1938	DNC
98	Guayalejo at Bridge in Road No. 1 Tams.	1,274	368,330	289.1	103.2	Aug., 1938	DNC
	(*l*) Panuco River Basin, Zone XI						
99	Tepeji at Taxhimay Dam, Hgo.	125	3,249	26.0	2.9	Oct., 1941	CNI
100	Tepeji at Tepeji, Hgo.	212	8,087	38.1	5.6	Sept., 1936	CNI
101	Tula near Binola Ranch, Hgo.	1,674	13,985	8.4	3.4	July, 1937	CNI
102	Tula near Ixmiquilpan, Hgo.	4,161	18,893	4.5	2.9	Oct., 1941	CNI
103	Tlautla near Jasso, Hgo.	239	10,736	44.9	6.9	July, 1938	CNI
104	Metztitlán near Venados Ranch, Hgo.	620	42,377	68.4	17.0	Oct., 1930	CNI
105	San Ildefonso at San Ildefonso Dam, Mex.	149	14,867	99.8	12.1	Aug., 1937	CNI
106	Guayalejo at San Gabriel dam site, Tams.	1,660	59,752	36.0	15.1	June, 1944	CNI

TABLE 6.—(*Continued*)

Reference No.[a]	River and site	Drainage area (sq miles)	Discharge (Cu ft per sec)	Discharge (Cu ft per sec per sq mile)	Myers rating, p (%)	Date	Authority[b]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	(*m*) Gulf of Mexico, Zone XII						
107	Tomatan at Station No. 8¼, Ver.	145	24,438	168.5	20.3	Sept. 22, 1944	CFE
108	Los Bobos at Martinez de la Torre, Ver.	532	141,258	265.5	61.3	Sept. 22, 1944	CNI
109	La Antigua at Villa Cardel, Ver.	1,342	22,495	16.8	6.1	July, 1936	CNI
110	Papaloapan at Quiotepec, Oax.	4,226	165,625	39.2	25.5	Sept. 22, 1944	CP
111	Papaloapan at Tuxtepec, Oax.	5,647	206,590	36.6	27.5	Sept. 24, 1944	CP
112	Papaloapan at Papaloapan, Oax.	7,834	284,282	36.3	32.2	Sept. 24, 1944	CP
	(*n*) North Central Plateau, Zone XIII						
113	Casas Grandes near Casas Grandes, Chich.	1,630	6,286	3.9	1.6	Sept. 30, 1941	CNI
114	Nazas at Palmito dam site, Dgo.	7,431	216,478	29.1	25.1	Sept. 8, 1944	CNI
115	Nazas at Fernández Canyon, Dgo.	12,560	151,358	12.1	13.5	Sept, 1917	CNI
116	El Oro, near Jesús Maria Canyon, Dgo.	3,293	134,548	40.9	23.4	Sept. 8, 1944	CNI
117	Ramos at Potrerillo Canyon, Dgo.	3,911	61,271	15.7	9.8	Sept. 8, 1944	CNI
118	Aguanaval near La Flor, Dgo.	7,942	10,206	1.3	1.1	Sept., 1941	CNI
119	Los Lazos at El Sauz, Zac.	472	8,264	17.5	3.8	Sept., 1943	CNI
	(*o*) Cuitzeo Lake Basin, Zone XIV						
120	Grande de Morelia at Cointzio Dam, Mich.	243	1,448	6.0	0.9	Aug., 1931	CNI
121	Querendaro near Querendaro, Mich.	106	3,920	37.0	3.8	Aug., 1941	CNI
	(*p*) Valley of Mexico, Zone XV						
122	Cuautitlán at Guadalupe Dam, Mex.	110	3,108	28.3	3.0	July, 1937	SCOP
123	Remedios at Molino Blanco, Mex.	75	5,933	79.1	6.9	May, 1939	SCOP
124	Tlalnepantla near Madin, Mex.	37	3,108	84.0	5.1	Oct., 1936	SCOP
125	Hondo at Rio Hondo, Mex.	59	6,710	113.7	8.7	June, 1941	SCOP
126	Chico de los Remedios at Cristo Ranch, Mex.	15	600	40.0	1.6	June, 1935	SCOP
127	Texcoco near Texcoco, Mex.	16	6,957	434.8	17.4	July, 1938	CNI
128	Ameca near Temamatla, Mex.	135	2,013	14.9	1.7	Sept., 1941	SCOP
129	Guadalupe Creek near Atlamaya, D. F.	7	1,942	277.4	7.4	Sept., 1942	SCOP
130	Magdalena at Anzaldo Dam, D. F.	42	918	21.9	1.4	Sept., 1933	SCOP
131	Texcalatlaco at Texcalatlaco Dam, D. F.	2	1,165	582.5	8.2	Sept., 1933	SCOP
132	Piedad at Colonia del Valle, D. F.	10	2,013	201.3	6.4	Sept., 1938	SCOP
133	Becerra near Viaducto, D. F.	3	953	317.7	5.5	Sept., 1935	SCOP
134	Totolica near Totolica, D. F.	10	1,519	151.9	4.8	July, 1941	SCOP
135	Tacubaya at Belem, D. F.	5	1,236	247.2	5.5	Sept., 1933	SCOP
136	Mixcoac at Mixcoac, D. F.	11	2,295	208.6	6.9	July, 1937	SCOP
137	Churubusco at Xoco, D. F.	58	3,496	60.3	4.6	July, 1931	SCOP

[a] See numbers in the key, inset Table 6(*b*). [b] Authorities: CNI—Comisión Nacional de Irrigación (National Commission of Irrigation); CFE—Comisión Federal de Electricidad (Federal Commission of Electricity in Mexico); IBC—International Boundary Commission, United States and Mexico; ENR—*Engineering News-Record;* DNC—Direction Nacional de Caminos (National Direction of Roads); CP—Comisión del Río Papaloapan (Papaloapan River Commission); and SCOP—Secretaria de Comunicaciones y Obras Públicas (Communications and Public Works Ministry). [c] Inset Table 6(*a*) is the key for zone numbers.

FIG. 7.—MAXIMUM FLOOD-FLOW PERCENTAGE RATINGS, p, IN THE MYERS FORMULA

four times larger than that of Mexico, has more than six times its average annual surface runoff, and that the runoff unit area is one and one-half times larger.

River Discharges

An estimate of the variation of discharge in Mexican rivers is possible by reference to Fig. 6, which includes mean hydrographs of some of the principal rivers. The great concentration of runoff in summer months occurs from May or June to September or October, which period accounts for more than 75% of the annual yield.

Maximum Discharges

Although, in the northwestern part of Mexico, maximum observed discharges have occurred in winter months, in the remainder of the nation the major discharges and floods are observed in summer months, with the appearance of humid winds and air masses. Even tropical cyclones are recorded in August and September. The data in Table 6 were prepared to show the unit discharge for the various drainage areas and for each of the regions into which Mexico has been divided. Fig. 7 shows the rating percentages—

$$p = \frac{Q}{100\,M} \qquad (1)$$

—in the Myers formula[6] of flood flows in Mexico, for comparison with other world areas. In Eq. 1, in addition to the rating percentage p, the flow Q is in cubic feet per second; and M is the area in square miles.

It is important to emphasize that the maximum discharges ever recorded in Mexico came from the rivers in the northeast region which originated in the storms produced by cyclonic disturbances. The next discharges, in order of maximum intensity came from the northwestern rivers where the humid air masses coming from the Pacific Ocean strike the sierra and deliver rainfalls of the cloudburst type. The intermountain plateau is more or less protected against violent storms such as those observed in the coastal regions and the maximum discharges are relatively minor.

Acknowledgments

The revised text and material presented in this paper were prepared by the writer after presentation to the ASCE Mexico City Meeting in July, 1949, before the Irrigation Division. The subject of the paper is part of the writer's work as chief of the Hydrology Section of the Water Resources Ministry of Mexico, of which Adolfo Orive Alba is the secretary. Aurelio Benassini, Assoc. M. ASCE, is chief engineer of the River Control and Irrigation Department. In preparing this paper, and in collecting data, the writer has been assisted by numerous persons without whose help it could not have been completed.

[6] "Hydrology," Oscar E. Meinzer, editor, McGraw-Hill Book Co., Inc. New York, N. Y., 1st Ed., 1942, p. 535.

AMERICAN SOCIETY OF CIVIL ENGINEERS

OFFICERS FOR 1950

PRESIDENT

ERNEST E. HOWARD

VICE-PRESIDENTS

Term expires January, 1951:

HENRY J. SHERMAN
ROBERT B. BROOKS

Term expires January, 1952:

FRED C. SCOBEY
ALBERT HAERTLEIN

DIRECTORS

Term expires January, 1951:

WILLIAM M. GRIFFIN
KIRBY SMITH
FRANCIS S. FRIEL
JULIAN HINDS
WEBSTER L. BENHAM
C. GLENN CAPPEL

Term expires January, 1952:

WALDO G. BOWMAN
MORRIS GOODKIND
HAROLD L. BLAKESLEE
PAUL L. HOLLAND
EDMUND FRIEDMAN
S. T. HARDING

Term expires January, 1953:

OTTO HOLDEN
FRANK L. WEAVER
GORDON H. BUTLER
LOUIS R. HOWSON
G. BROOKS EARNEST
WALTER J. RYAN
GEORGE W. LAMB

PAST-PRESIDENTS

Members of the Board

R. E. DOUGHERTY
FRANKLIN THOMAS

TREASURER
CHARLES E. TROUT

EXECUTIVE SECRETARY
WILLIAM N. CAREY

ASSISTANT TREASURER
GEORGE W. BURPEE

ASSISTANT SECRETARY
E. L. CHANDLER

PROCEEDINGS OF THE SOCIETY

SYDNEY WILMOT
Manager of Technical Publications

HAROLD T. LARSEN
Editor of Technical Publications

COMMITTEE ON PUBLICATIONS

WALDO G. BOWMAN

FRANCIS S. FRIEL
S. T. HARDING
OTTO HOLDEN
LOUIS R. HOWSON
KIRBY SMITH